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FLEXIBLE MANUFACTURING SYSTEM HANDBOOK

VOLUME I: EXECUTIVE SUMMARY

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by Charles Stark Draper Lab., Inc.
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Flexible Manufacturing Technology is a means to increase productivity for manufacturing environments in the middle ranges of production volume. It is effective for "one of a kind" and true "mass production" quantities. Volumes I through IV of this handbook help determine if a flexible machining system (FMS) will be cost effective for a given application. These volumes explain the configuration and procurement of a FMS, and its impact on the existing organization. The fifth volume of the handbook details the computer programs for the

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The Charles Stark Draper Laboratory, Inc.
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PREFACE

This Handbook was written for the U.S. Army/Tank Automotive Command to help increase productivity in the manufacture of Army vehicles by aiding in the acquisition and use of Flexible Manufacturing Systems technology. It could not have been written without the encouragement and assistance of members of the U.S. Army/Tank Automotive Command (TACOM) in Warren, Michigan, and of the U.S. Army/Development and Readiness Command (DARCOM) in Alexandria, Virginia.

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1.0 INTRODUCTION

Flexible Manufacturing Systems (FMSs) represent a relatively new strategy to increase productivity. The technology is especially attractive for manufacturers who produce in the middle ranges of production volumes, neither "mass" production nor "one of a kind".

Today's unpredictable market environment demands low-cost solutions that provide quick product start-up, adaptability and responsiveness to changes in demand, and the capacity to easily resurrect out-of-production designs. In many instances, FMSs provide a direct hardware/software solution to this threefold management challenge.

The adoption of FMS technology requires that one address many questions beforehand. This five-volume handbook is intended to help answer questions such as:

Why acquire an FMS?

Which manufacturing applications are best served by FMS?

What requirements does an FMS place on the existing organization?

Who designs an FMS, and how is it done?

This handbook provides a methodical approach to answering these questions. But it is not a "cookbook"; it cannot be. Each application of FMS technology is unique, therefore, the guidelines presented are fairly general.

The handbook has a pyramidal structure. It proceeds from a brief overview and summary to aid broad decision making at top corporate levels (Volume I), through a detailed description of FMS technology and the more significant components and subsystems in Volume II. Volume III presents the specific steps and analyses that must be performed to justify, purchase, and operate an FMS; The remaining volumes detail the technical material and software packages required in the acquisition and operation of an FMS.

2.0 WHAT IS A FLEXIBLE MANUFACTURING SYSTEM?

An FMS can be defined as a "computer-controlled configuration of semi-independent work stations and a material handling system designed to efficiently manufacture more than one part number at low to medium volumes". Figure 1 shows a conceptual drawing of an FMS. The definition and the illustration highlight the three essential physical components of an FMS:

- Standard numerically-controlled machine tools.
- A conveyance network to move parts and perhaps tools between machines and fixturing stations.
- An overall control system that coordinates the machine tools, the parts-moving elements, and the workpieces.

In most FMS installations, incoming raw workpieces are fixtured onto pallets at a load station set apart from the machine tools. They then move via the material handling system to queues at the production machines where they are processed. The flow of parts in the system is directed by the control computer which acts as the traffic coordinator. In properly designed systems, the holding queues are seldom empty, i.e., there is a workpiece waiting to be processed when a machine becomes idle. And when pallet exchange times are short, the machine idle times become quite small.

The number of machines in a system typically ranges from 2 to 20 or more. The conveyance system may consist of carousels, conveyors, carts, robots, or a combination of these. The important aspect of these systems is that the machine, conveyance, and control elements combine to achieve enhanced productivity and maximum machine utilization without sacrificing flexibility.

FMS technology has a relatively brief history. The original concept emerged in the mid- to late-1960s, a logical outgrowth of progress in applying numerical control and attempts at factory-wide direct numerical control. By the early 1970s, a number of FMSs were installed, and throughout that decade one by one they became operational, following a problem-shakedown period typical of new technology.

There are now well over a dozen full-scale FMSs in operation in the U.S. and abroad plus a number of installations that use FMS concepts. Not only is the technology proven, it is increasingly available: a growing number of machine-tool builders are able to supply complete systems.

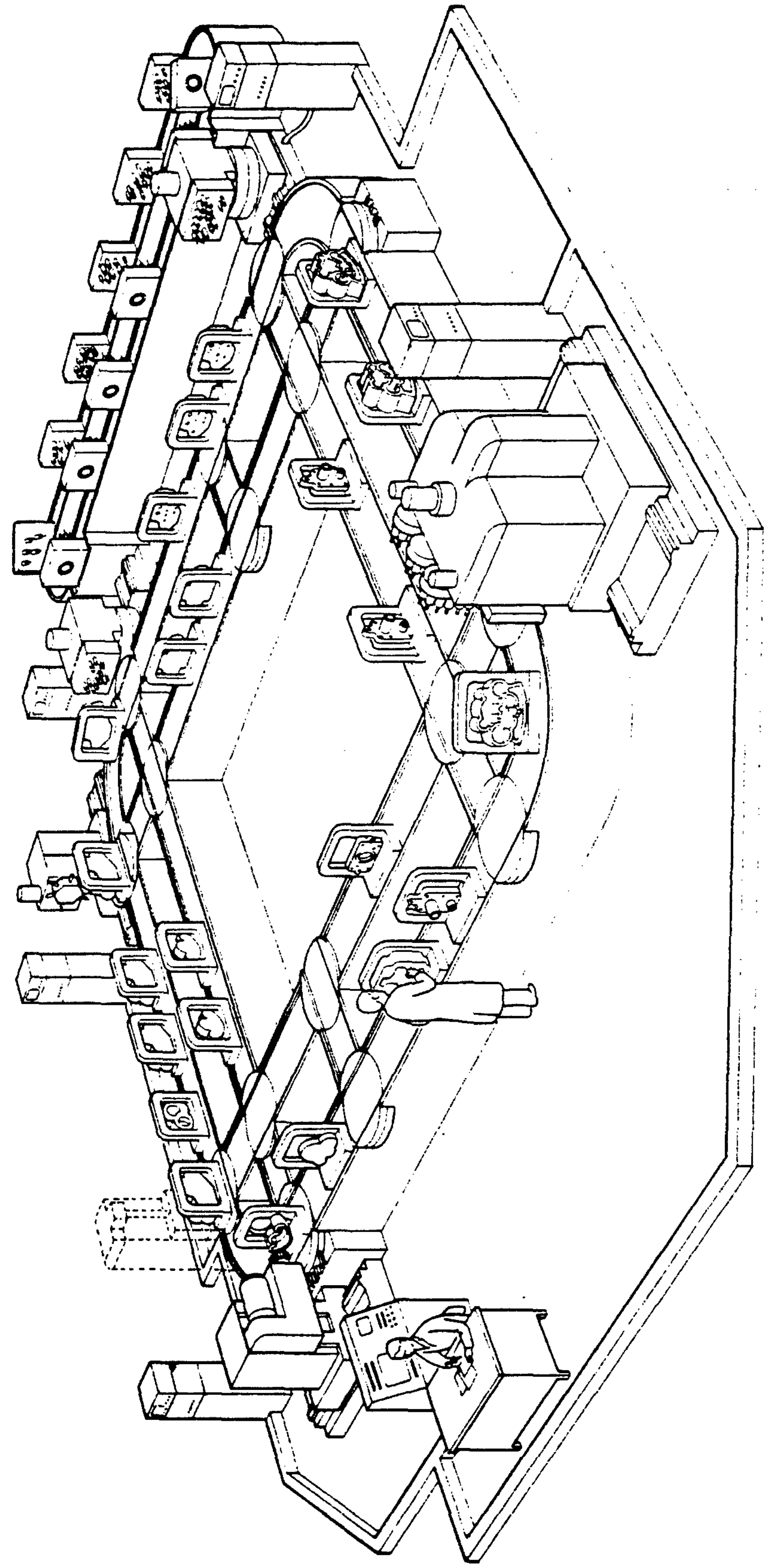

Figure 1. Conceptual Drawing of an FMS

2.1 FMS BENEFITS

There are many benefits to be obtained through the use of FMS technology:

- High Capital Equipment Utilization

  Typically, the throughput achieved for a set of machines in an FMS will be up to three times that achieved by the same machines in a stand-alone job shop environment. The FMS achieves high efficiency by having the computer schedule every part to a machine as soon as it is free; simultaneously moving the part on the automated material handling system and downloading the appropriate NC program to the machine. In addition, the part arrives at a machine already fixtured on a pallet (this is done at a separate load station) so that the machine does not have to wait while the part is set-up.

- Reduced Capital Equipment Costs

  The high utilization of equipment results in the need for fewer machines in the FMS to do the same work load. Reduction of 3:1 is common when replacing machining centers in a job-shop situation with an FMS.

- Reduced Direct Labor Costs

  Since machines are operated completely under computer control, machinists are not required to run them. The only direct labor involved is that of less skilled personnel to fixture and defixture the parts at the load station, plus a system supervisor. However, labor cost reduction is somewhat offset by the need in the factory for skills which may not be currently present, such as computer specialists.

- Reduced Work-in-Process Inventory and Lead Time

  The reduction of work-in-process in an FMS is quite dramatic when compared to a jobshop environment; reductions of 80 percent have been reported at some installations. This reduction may be attributed to a variety of causes which reduce the time a part is <u>waiting</u> for metal-cutting operations, such as:

  - The concentration of all the equipment required to produce parts in a small area (within the FMS).

  - The reduction in the number of fixturings required and the number of machines a part must travel to because processes are combined on machining centers.

  - Efficient computer scheduling of parts batched into and within the FMS.

- Responsiveness to Changing Production Requirements

  An FMS has the inherent flexibility to manufacture different products as the demands of the marketplace change or as engineering design changes are introduced. Also, required spare part production can be mixed in without significantly disrupting the normal FMS production activities.

- Ability to Maintain Production

  Many FMSs are designed to degrade gracefully when one or more machines fail. This is accomplished by incorporating redundant machining capability and a material handling system which allows failed machines to be bypassed. Thus, throughput is maintained at a reduced rate.

- High Product Quality

  A sometimes overlooked advantage of an FMS, especially when compared to NC machines that have not been federated into a cooperative system, is improved product quality. The high level of automation, reduction in the number of fixturings and the number of machines visited, better designed permanent fixtures, and greater attention to part/machine alignment all result in good individual part quality and excellent consistency from one workpiece to another. This also results in greatly reduced costs of rework.

- Operational Flexibility

  Operational flexibility offers another increment in productivity. In some systems, the FMS can run virtually untended during the second and third shifts. This nearly "unmanned" mode of operation is currently the exception rather than the rule. But it should become increasingly common as better sensors and computer controls are developed to detect and to handle unanticipated problems such as tool breakages, part flow jams, etc. In this operational mode, inspection, fixturing, and maintenance can be performed during the first shift.

- Capacity Flexibility

  With correct planning for available floor space, an FMS can be designed for low production volumes initially and, as demand increases, new machines can be added easily to provide the extra capacity required.

2.2 WHEN TO USE FMS TECHNOLOGY

Can these benefits be realized in a given manufacturing situation? The first question to ask is "Are the parts to be manufactured in the so-called midvolume range?". Here, the flexibility of the system to manufacture a variety of parts allows the aggregation of <u>all</u> suitable part types to reach the midvolume range, even though the yearly production volume of some parts may be low.

Parts need not appear similar in shape or geometry, yet they should share certain broad characteristics that will allow them to be grouped into families. Parts should be roughly similar in size and weight, made of compatible materials, and the manufacturing processes should be broadly compatible. Such patterns of similarity usually already exist in conventional plants; in metal-cutting operations, for example, large boxy -- or "prismatic" -- workpieces seldom if ever get in the way of small turned forgings. Another prerequisite, at least for the current generation of FMSs, is that only modest precision is required of the final part. Future generations of FMS are expected to produce increasingly precise parts.

Aggregate production suitable for FMS application has typically ranged from yearly rates of 1000 to 100,000, but the specific processes and process times will decide the profitability of an FMS. In general (Figure 2) at very low-production volumes, stand-alone NC machines (job shop) are the best choice -- having the flexibility to adapt to produce a few each of very different part types. At very high-production volumes, a very inflexible transfer line will be the most cost-effective alternative.

Figure 2 implies that FMSs are the only technology to be used in the intermediate production volume range, but this interpretation depends upon how an FMS is defined. A restrictive definition of an FMS will exclude certain technologies which can be applied economically to the manufacture of medium-volume parts. Such techniques include: unmanned machining centers, manufacturing cells, and flexible transfer machines. The potential buyer in conjunction with responsible system suppliers must decide which version of the technology is appropriate in a given situation.

2.3 CHALLENGES TO MANAGEMENT AND THE ORGANIZATION

Typically -- as with any state-of-the-art technology -- the successful acquisition of an FMS requires the organization have an influential "believer" in the technology to champion the concept. Ideally, this individual is technically oriented and will head the buyer's team; he will provide continuity for the project as well as being the primary contact for the FMS supplier. The acquisition of an FMS requires the understanding and support of the plant's personnel as well as that of top management.

Compared to stand-alone NC machine tools, an FMS is complicated, consisting of many interconnected components -- from the computerized control system that oversees the operation with its hardware, software, sensors, actuators, and communication links, to the automated material handling system with its carts, pallet shuttles, and/or robots. Due to the sparse manning of the system, strict tool-management discipline for a large number of tools, meticulous incoming inspection, and rigorous attention to maintenance is required. In an automated system, machinists will not fix problems "on the fly".

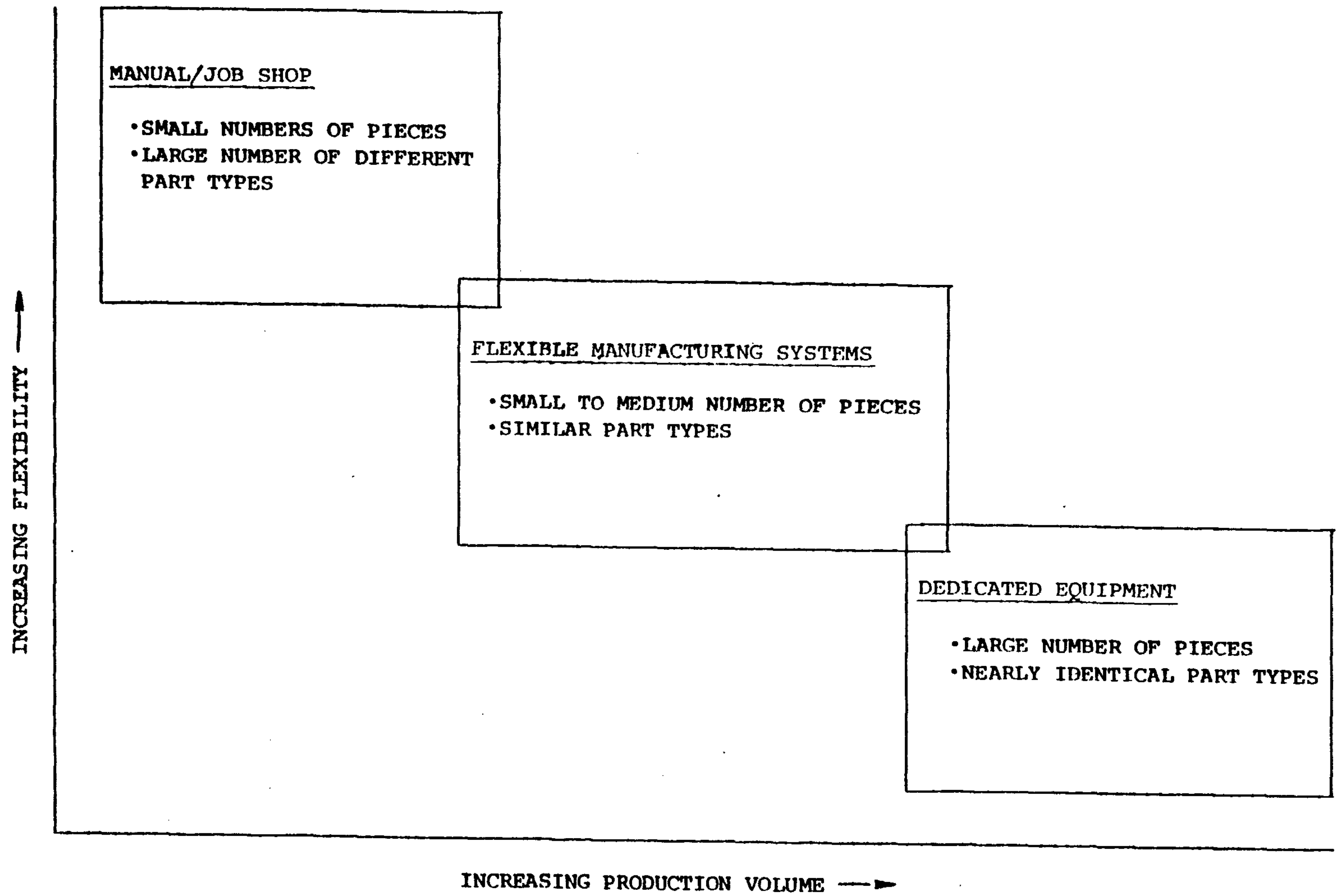

Figure 2. Manufacturing Technology Application Areas

All departments -- from accounting through quality control and beyond -- feel the impact of an FMS installation. Not only must systems and procedures be reorganized, but the attitudes and skills of people in the company may have to be altered and upgraded. It is important to recognize this at the beginning.

An appropriate infrastructure is needed. The organization should have a staff of technical and financial planners, and it is beneficial to have a computer facility staffed with personnel experienced in simulations and real-time hardware/software problem solving.

And finally, getting a complex FMS up and running requires full cooperation between seller and buyer for a considerable period of time. Even with operations personnel working side by side with the vendor during installation, it may take up to 6 months before the system reaches the designed production volume.

If the FMS technology appears to be compatible with your strategic goals, then a more detailed examination of the specific application(s) is warranted.

3.1 STEPS IN THE ACQUSITION OF AN FMS

A typical FMS is a complicated system that requires wholehearted top management support and the employees' union or labor council to achieve success. In order to avoid errors in specification, design, and operation, it is important to adopt a methodical approach. Table 1 lists some of the important points to consider in the various stages of FMS acquisition.

The remaining volumes of this handbook consider these questions in more detail.

3.2 ESTABLISHING THE FMS TASK FORCE

Once the preliminary decision to procure an FMS is made, the next step is to organize a task force. This group will define goals, develop a schedule, learn the current state of the technology, structure bid invitations, evaluate the resulting proposals, and plan for the system's installation and operation.

The task force should be headed by a high-ranking member of the organization, for example, the Vice President for Manufacturing. It should include a representative from nearly every department that will be affected. Members might well include a technical planner, a financial planner, a manufacturing-operations engineer, a systems engineer, a computer engineer, a product-design engineer, and a maintenance engineer.

Additional members, such as a union representative, can be brought aboard as the need arises, either as full task force members or as consultants.

Since task force members will serve as a primary means of communication between the people who install the system and those who will run it, the members should be motivated, knowledgeable, and respected in their own departments.

Table 1. Steps in FMS Implementation

Step 1	Step 2	Step 3
<u>Select Parts and Machines</u> • Preselect from available candidates those parts and machines having FMS-compatible attributes. • Calculate current production cost of each part. • Estimate FMS manufacturing cost for each part. • Use either manual or computerized methods to select the most economically beneficial parts and machines. • Perform investment analysis to determine if FMS is a cost-effective alternative.	<u>Design Alternative FMS Configurations</u> a) <u>Estimate the Work Content of the Selected Parts</u> • Develop FMS fixturing concepts for the selected parts. • Process plan each part in detail, constrained by the limited tool capacity of an FMS. • Estimate production requirements for each part. • Calculate part cycle times and tool usage. b) <u>Design Configurations</u> • Choose specific vendors' equipment in each machine class. • Estimate the minimum number of machines (spindles) for each machine class. • Modify this number of machines to account for shop and system efficiency, limited tool storage capacities, and desires for machine redundancy. • Add desired nonmachining processes, such as automated inspection, a material handling system, etc. • Develop variations on the design configuration.	<u>Evaluate Candidate FMS Configurations</u> • Simulate the operation of each configuration. • Improve the configuration designs until each provides satisfactory performance measures or is rejected. • Perform detailed investment analyses. • Examine and evaluate intangibles, such as flexibility, accuracy, etc. • Choose the configuration which best satisfies the investment and intangible analyses.

Table 1. Steps in FMS Implementation (Continued)

Step 4

Write a Request-for-Proposal (RFP)

- Write an RFP that conveys your findings and desires for an FMS.
- Avoid overspecification; allow the FMS vendors to be creative and competitive in designing an FMS for your situation.

Step 5

Evaluate Vendor Proposals

- Verify and evaluate vendor proposals using simulation and economic analysis.
- Evaluate the degree of success of each proposal in satisfying your nonquantifiable requirements, such as flexibility, expandability, etc.
- Choose the proposal which best satisfies your company's requirements.
- Work with the vendor to develop detailed specifications and prices.
- Place an order.

Step 6

Prepare for, Install, and Shakedown the FMS

- Select and educate personnel to operate and maintain the FMS.
- Involve the quality control and production control departments in preparing for the FMS.
- Develop a preventative maintenance plan and spare parts lists for the FMS.
- Prepare the FMS site.
- Assist vendor with installation and shakedown.
- Perform FMS acceptance tests.

Step 7

Operate the System

- Schedule parts
- Batch production if necessary
- Allocate parts and tools to machines
- Balance machine loads
- Use a decision support system to optimize daily operations in the face of machine failure and changing part requirements.

3.3 FMS IMPLEMENTATION PLAN

The assembled task force should begin by defining goals and laying out a rough schedule for system acquisition and use. Some plan elements would include the degree of flexibility desired, the minimum acceptable level of reliability (availability), the system's probable location, the means of financing, the desired return-on-investment, the goal for reduction in inventory, the average machine utilization goal, etc.

A key plan element is the determination of which part family or families will be run on the FMS as well as the anticipated production rates. The specification for the family of parts will include a list of operations -- milling, drilling, tapping, turning, boring, punching, stamping, hardening, etc. It will also include the required maximum workpiece envelope size, the appropriate type of fixturing, and the materials that will be processed.

Further, the task force should identify potential interface problems between the planned FMS and the present manufacturing system. Such problems might occur in the areas of accounting, production planning, inventory control, tool management, computer facilities, and labor relations.

3.4 THE REQUEST-FOR-PROPOSAL

Following some interaction with potential FMS suppliers to determine the current state-of-the-art, and after some team members visit an existing FMS facility (where feasible), the team's next task is to draft a set of specifications. These will form the core of the formal Request-for-Proposal (RFP). Additional items, such as installation schedule, acceptance test descriptions, training requirements, and computer simulation requirements, will round out the RFP.

In order to speed up the FMS acquisition process, it is advisable to show a preliminary copy of the bid invitation to potential vendors for comments. Also, prior to issuing the final version of the RFP, it may be advisable to fund a small contract with an FMS vendor or a consultant to do a detailed analysis of the candidate FMS. Such a study would include a computer simulation of the system.

3.5 EVALUATIONS

Vendor proposals will cite most of the system costs, and these, of course, should be compared. Other costs that the purchaser may have to add into the calculations include those for site preparation.

More difficult to evaluate will be the extent to which each proposed FMS will meet or exceed the specifications set in the RFP. Computer simulations of each proposed system will help predict productivity. The reliability and accuracy of each FMS, as well as other intangibles, are more difficult to predict and compare. Therefore, the reliability and accuracy experience obtained on similar installations should be examined.

4.0 SUMMARY

Machining centers (and turning centers) are very flexible in their capabilities, yet they effectively automate production only one part at a time. Dedicated production equipment, such as transfer lines, on the other hand, often sacrifice ease of changeover for repetitive accuracy and speed of throughput for "mass" production.

In the middle lies an opportunity to economically automate midrange production volumes in a way to achieve responsiveness. FMS technology addresses this area of manufacturing.

FMS technology represents an opportunity to use computer techniques to boost productivity, by increasing machine use and making a manufacturing plant extremely responsive to changes in demand.

The succeeding volumes of this handbook describe the available FMS technology (Volume II), provide more detailed information for planners (Volume III), provide extensive background information (Volume IV), and describe available software packages (Volume V).

Taken as a whole, this handbook provides guidance. The book's users must provide the expertise, the resources, and the will.

5.0 ACKNOWLEDGEMENTS

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